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THE CEBAF PROJECT

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1. HISTORY AND OVERVIEW OF THE PROJECT

Essential information about the Continuous Electron Beam Accelerator Facility is summarized below:

Energy:	0.5-4.0 GeV
Duty factor:	90%
Current:	120-240 μA
Location:	Newport News, Virginia
Cost:	$225M (including inflation and contingencies)
Timetable:	Start construction - late 1986 First beam 5 years later
Funding:	Virginia - $2M for the period July 1, 1984 through July 1, 1986
	U. S. Department of Energy: $1M FY '84 $3.5M + $0.3M (PE&D) FY '85 $5.0M asked for FY '86

The layout of the facility, designed by J. S. McCarthy, B. Norum, and R. York, from the University of Virginia, is shown in Fig. 1. The 2 GeV linac, which has a pulse repetition rate of 1000 Hz, produces pulses of electrons 1.2 μs long. To achieve energies in excess of 2 GeV, the beam can be re-circulated once to give energies of up to 4 GeV. The beam can then be injected into the pulse stretcher ring (PSR) where each pulse (approximately 360 m long) just fills the ring. While the beam is coasting around the ring (approximately 1000 times before the next pulse arrives) it can be extracted continuously and fed simultaneously into the three end stations. The two largest end stations shown in Fig. 1 are designed to take the full current and are equipped with the long beam dumps shown in the figure. The middle end station is designed for tagged photons or low electron current work; it is unshielded and has no long beam dump. If a pulsed beam is sufficient for a particular experiment, it can be transported directly from the linac into either (or both) of the high current end stations.

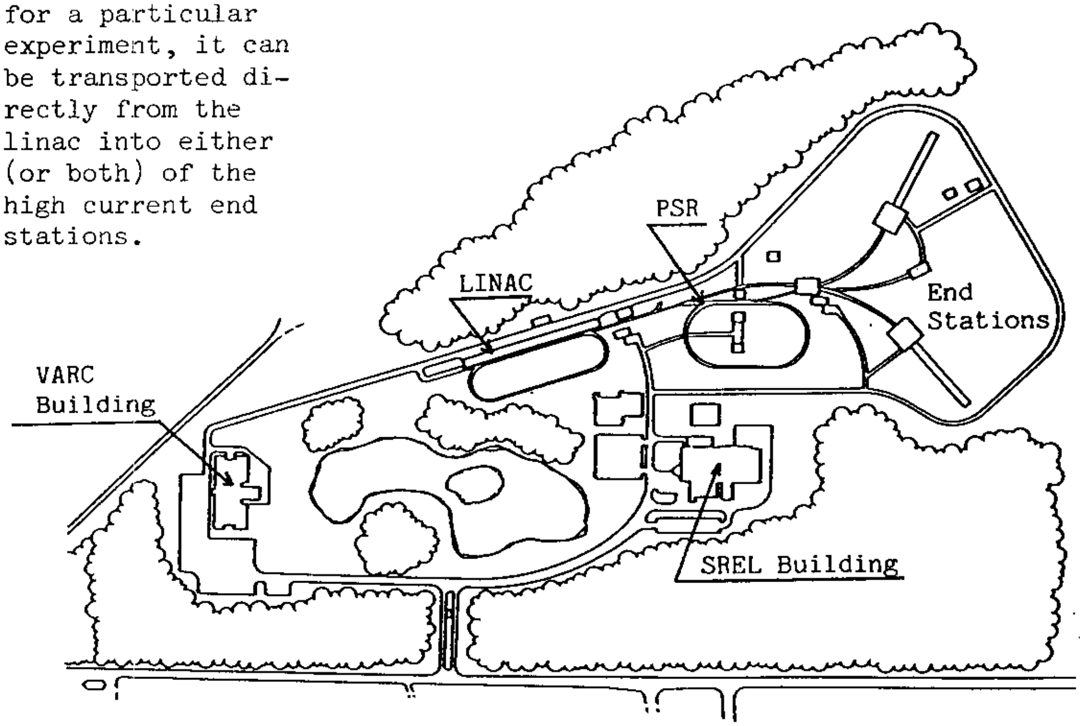

Fig. 1.

Two buildings already exist on the site. The VARC (Virginia Associated Research Campus) building has been in continuous use for many years, and is currently the main building for the project. It has a library, conference room, and offices for over 90 scientific and administrative personnel. The SREL building is the former location of the Space Radiation Effects Laboratory, which closed in 1979. It has a high bay area and a reinforced floor ideal for the assembly of heavy equipment, or for the testing and fabrication of accelerator components. The building also contains office and laboratory space which will be renovated before it is occupied by CEBAF personnel. The City of Newport News, which enthusiastically supports the project and has purchased 200 acres to give to CEBAF, has a large research park under development on one side of the site and plans to develop another research park on the other side.

The nuclear physics community in the United States has been interested for many years in a CW electron accelerator in the GeV range. Reports from the Friedlander and Livingston panels, released in 1977, called for such an accelerator. The first U.S. long-range plan for nuclear science, prepared by the Nuclear Science Advisory Committee (NSAC) in January 1980, gives a high priority to the construction of a 2 GeV CW electron accelerator for nuclear physics. Following the release of this first long-range plan, the U.S. community, including physicists from Southeastern institutions, began a serious study of future directions in electromagnetic nuclear physics. A workshop with this name was organized by the Bates-MIT Users Group, and the result of this study was published in the summer of 1981[1]. This study, known as the "Blue Book", contains 26 detailed mini-proposals describing important experimental programs which it would be desirable to carry out in the future.

The history of the Southeastern project parallels the national history closely. After a conference on electron accelerators held at the University of Virginia in 1979, James McCarthy realized that the linac/pulse stretcher ring concept made it possible to construct a multi-GeV CW electron accelerator with existing technology, and his group began work on the design. Representatives of universities in the Southeast met for the first time on May 16, 1980. The result was the formation of the Southeastern Universities Research Association (SURA) which was incorporated in Virginia on August 21, 1980. One of the major reasons for forming SURA was to provide university support for the electron accelerator being designed at the University of Virginia. Realizing that the technology was already available, that the design for the accelerator existed, and that there was strong support at the national level for such an accelerator, SURA submitted its proposal to build a National Electron Accelerator Laboratory (NEAL) at the end of 1980.

The question of the best choice of energy for the new accelerator became a sharp issue in 1981, and an NSAC subcommittee chaired by Peter Barnes of Carnegie-Mellon University was organized to study this issue. Its report[2], released in the fall of 1982, recommended that the new accelerator have an energy of 4 GeV. SURA submitted its second NEAL proposal[3] in October, 1982. Shortly afterwards, in December, the Department of Energy and the National Science Foundation received proposals from Argonne National Laboratory, MIT, National Bureau of Standards, and the University of Illinois.

A panel chaired by D. Allen Bromley from Yale University, was formed to study the five proposals to make recommendations on which ones should be funded[4]. This panel conducted a very intensive review of all of the proposals early in 1983; each proposer was given the opportunity to submit written questions to all the others, asked to prepare written answers to the questions which it received, and a public meeting was held on February 17 and 18 to give each group a chance to present and defend its proposal before the others and before the Bromley Panel. On April 22, NSAC endorsed the recommendation of the Bromley Panel that the SURA proposal be selected.

The most recent NSAC long-range plan, released in December, 1983, reaffirms its earlier recommendation for the earliest possible start on the construction of CEBAF. Recently, a subcommittee chaired by Eric Vogt was appointed by NSAC to consider again the scientific merit of a 4 GeV CW electron accelerator, in view of recent scientific developments. Their principal recommendation, released in September of 1984, and endorsed by NSAC is stated below:

> The subcommittee endorses the recommendation that the first priority major construction project for nuclear physics be a 4 GeV CW electron accelerator.

President Reagan's budget for FY '86 (which begins October 1985) contains $5M for research and development for CEBAF. The following paragraph was included in the FY '86 budget highlights:

> The fiscal year 1986 nuclear physics program will continue advanced accelerator research for the future construction of the Continuous Electron Beam Accelerator Facility project sponsored by the Southeastern Universities Research Association. This will be a facility centering on an electron linear accelerator/stretcher ring complex capable of delivering intense, continuous beams in the energy range from 500 to 4000 million electron volts (MeV). The intensity of the beam, in combination with multimillion electron volts (GeV) energy and a unique high duty factor, will make this facility unmatched in the world.

The staff of the facility has been growing steadily since the initial funding in 1984. At the time of writing (April 1985), there were 36 full time employees, including 17½ original VARC positions supported by the Commonwealth of Virginia through the College of William and Mary. A Search Committee, chaired by Edward Knapp, recommended that Hermann A. Grunder be made director of the facility; he has accepted the position and begins work on May 1.

SURA, which began originally with nine institutions, has grown steadily and now includes 34 members. Its President is Harry Holmgren of the University of Maryland.

I now turn to a discussion of the physics program proposed for CEBAF. Since Bernhard Mecking has recently joined the project, and will also be speaking about CEBAF, I will limit my remarks to a brief overview of the program, followed by a short description of a few of the proposed experiments. Other aspects of the program, including a discussion of the proposed experimental equipment, will be described by Mecking.

2. PROPOSED PHYSICS PROGRAM

The specific experimental programs proposed fall into four major categories:

(i). Structure of Light Nuclei - including measurements of wave functions, study of the role of color degrees of freedom, and, for example, separation of the deuteron monopole and quadrupole form factors.

(ii). Structure of Mesons and Baryons - including measurements of the kaon and neutron form factors, and study of the vector mesons and excited baryons.

(iii). Influence of the Nuclear Medium on Hadronic Interactions - including study of the Δ propagation through a nuclear medium, NN correlations through the (e, e'NN) reaction, production of hypernuclei by the (γ,K) reaction, and influence of the nuclear medium on the hadronization of quarks.

(iv). Weak Interactions - including study of parity violating effects in eN scattering and use of nuclei to test the standard model.

The long range goal of the CEBAF is to study the clustering of quarks in the nuclear medium, the role of color degrees of freedom in nuclei, and non-perturbative aspects of QCD.

I will begin with a typical coincidence experiment in which two particles in the final state, the scattered electron and an outgoing nucleon, are measured simultaneously. Such (e,e'N) measurements contain important new information not obtainable from single arm measurements. If meson exchange effects or final state interactions are small, the electromagnetic interaction could be calculated from the diagram shown in Fig. 2. The triply differential cross section obtained from this diagram is given by

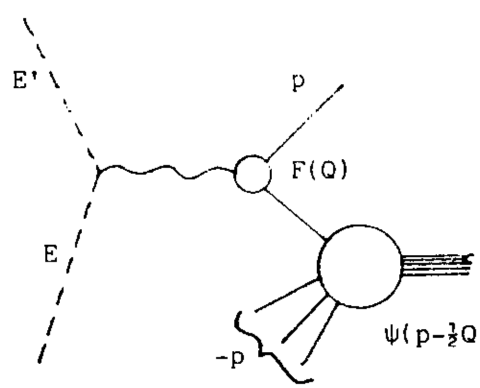

Fig. 2.

$$\frac{d^3\sigma}{d\Omega dE' d\hat{p}} \simeq \sigma_M \; |F(Q)|^2 |\psi(p - \frac{1}{2} Q)|^2 \qquad (1)$$

where, as usual, the scale of the overall cross section is set by the Mott cross section, F(Q) is the form factor of the nuclear constituent, and $\psi(p - \frac{1}{2} Q)$ is the relativistic wave function of the struck nucleon. The wave function depends on the relative momentum of the struck nucleon with respect to the other nuclear constituents, and, as can be seen from Fig. 2, is related to the covariant vertex function in which the struck nucleon is off-shell and the other nucleons and the initial nuclear system are on-shell. Eq. (1) shows us, therefore, that such measurements can in principle give us a direct measurement of the square of the relativistic wave function. (In practice, of course, final state interactions and meson exchange effects introduce corrections to this simple picture which may be significant.)

For comparison, the same simple theory gives the following expression for the single arm cross section

$$\frac{d^2\sigma}{d\Omega dE'} \simeq \Sigma_\beta \sigma_M |F_\beta(Q)|^2 \int d^2\hat{p} |\psi_\beta(p - \frac{1}{2} Q)|^2 \tag{2}$$

This expression differs from Eq. (1) in two important respects. First, the direction of the momentum of the final struck particle is integrated over, which means that the expression will always be dominated by that part of the phase space where the relativistic wave function has a maximum, making it difficult to measure the wave function in regions where it is small. A second difference is the sum over β, where β labels the different Fock space components of the wave function. In cases where we wish to study a particularly small Fock space component, such as the $\Delta\Delta$ contribution to the deuteron, it is a distinct advantage to be able to look at the final hadronic particles and use them as a means to select against the larger Fock components.

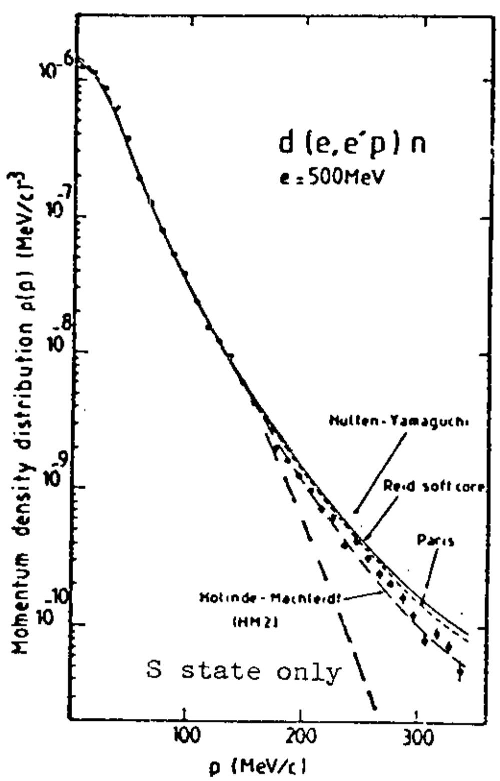

Fig. 3.

A program of such measurements has already been started at Saclay. Fig. 3 taken from reference 5, shows the results of (e,e'p) measurements from the deuteron. I have added to the figure a curve which shows roughly how the momentum distribution would fall if the deuteron had only an S state; clearly, the data is very sensitive to the D state component which in turn is a measure of the strength of the tensor force.

Similar results have been obtained for the 3-body system from Saclay $^3He(e,e'p)d$ and $^3He(e,e'p)np$ data[6]. Fig. 4, taken from reference 6, shows

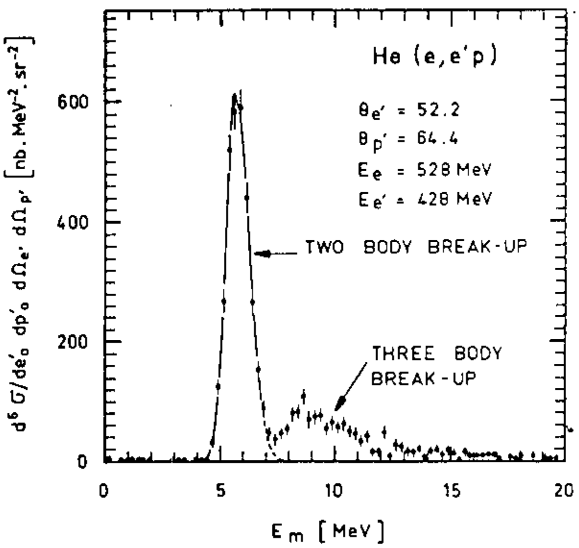

Fig. 4.

how the 2- and 3-body contributions can be separated from one another, and Fig. 5 shows the momentum space dependence of each of these separate Fock components. At CEBAF we will be able to extend these measurements to much higher momentum transfer, and to study more exotic processes.

An example of such an exotic process is the N*(1688)p component of the deuteron wave function[7]. The idea here is to separate the pre-existing N*p component of the deuteron wave function, shown in Fig. 6a, from other contributions which could give rise to the same final state. These are photo-production of the N*, shown in Fig. 6b, and production of the N* in a final state interaction, shown in Fig. 6c. With CEBAF, one has sufficient energy to choose the kinematics so that the momentum of the spectator nucleon cannot be less than 350 MeV/c and that the

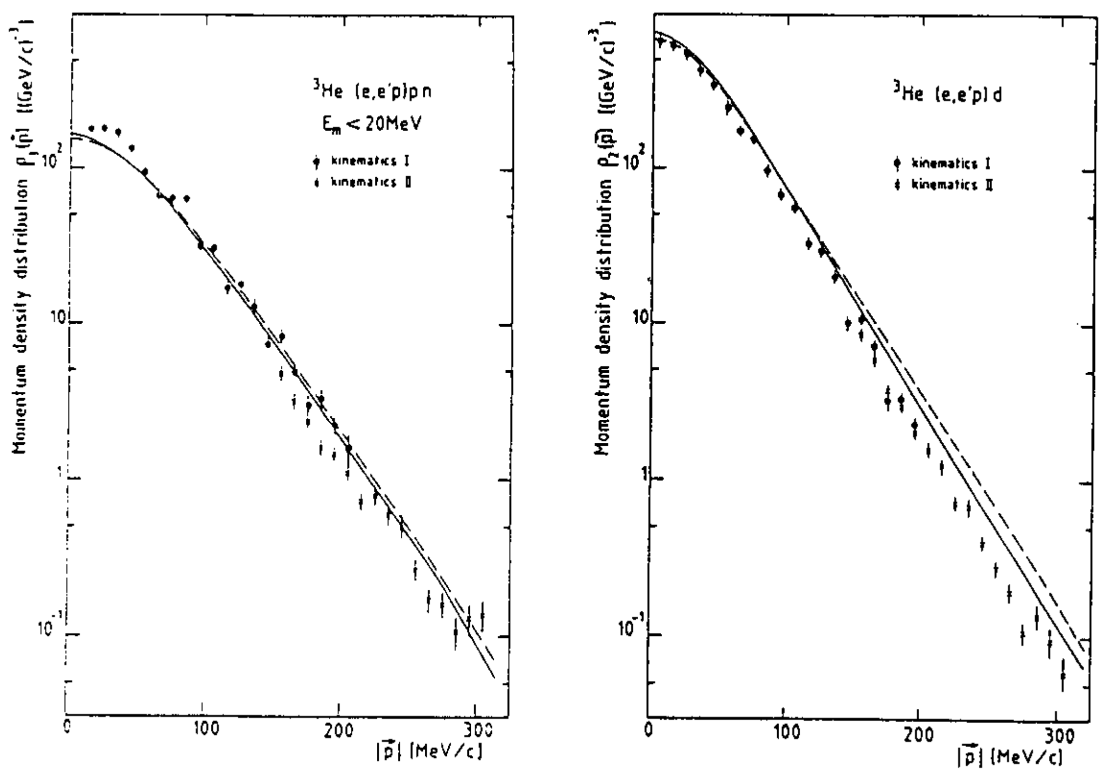

Fig. 5.

kinetic emergy of the final state N*p system is bigger than 175 MeV. The first condition ensures that the N* wave function is comparable to the D state component of the deuteron, both of which tend to peak in the vicinity of 350 MeV/c and are larger than the S state wave function at these high momenta. The second condition ensures that final state interactions will be kept to a minimum. In reference 7 it was found that pre-existing N*p components as large as 0.1% could be measured in this way.

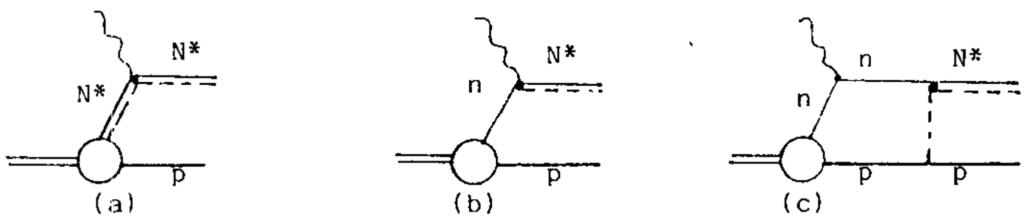

Fig. 6.

While electron energies as high as 1 GeV are not required for many experiments which probe the structure of heavy nuclei, there are some very important classes of measurements which require energy in excess of 2 GeV. Two such measurements, which look very promising, will now be described.

Two nucleon knockout, through the process (e,e'2N) appears to be a very promising way of studying nucleon-nucleon correlations. Several kinematic configurations can be devised for observing the two outgoing nucleons. In one case[8], the two nucleons come out parallel to each other, and are detected in a single spectrometer. If the two outgoing nucleons have a large momentum with respect to the rest of the nucleons in the nucleus, final state interactions will be reduced, and one hopes that the process will be dominated by the diagram shown in Fig. 7. The multiply differential cross section obtained from this simple diagram is proportional to the probability that the two nucleons detected in the final state had initial momentum p_1 and p_2. If $p = \frac{1}{2}(p_1 - p_2)$ is the relative momentum between these two nucleons, then the cross section is directly proportional to the square of the momentum space correlation function, which is a function of the quantity p. Initial estimates suggest that these

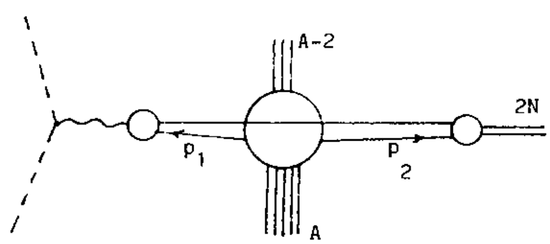

Fig. 7.

measurements require electron energy in excess of 3 GeV, high duty factor and intense beams.

Another program which looks very promising for the study of nuclear structure is the production of hypernuclei by the (γ,K) reaction[9]. Figure 8a shows the basic process by which the hypernucleus is formed.

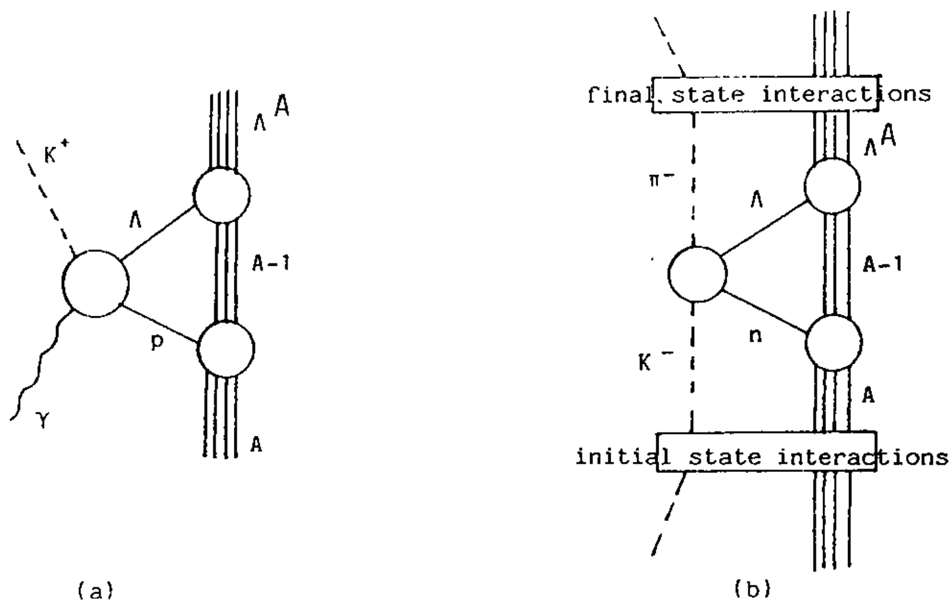

Fig. 8.

This is to be compared with the process by which hypernuclei are formed using K^- beams, shown in Fig. 8b. One of the advantages which the (γ,K) reaction has over the conventional (K^-,π^-) reaction is that both the photon and the K^+ are very weakly interacting particles, so that the initial and final state interactions tend to be fairly small and can be regarded as corrections to the basic process, Fig. 8a. This is not the case for the (K^-, π^-) reaction, where initial and final state interactions are very large because both the K^- and the π^- interact strongly. T. W. Donnelly who has popularized these studies, likes to emphasize the fact that the strong interactions of the K^- and π^- probes would make it impossible to deposit a Λ particle in the center of lead, whereas this can be done with photons. Another difference between the (γ,K) reaction and the (K^-,π^-) reaction is that the former will excite both unnatural and natural parity states, whereas the latter will strongly excite only natural parity states. This program would be an exciting, totally new way to study hypernuclei, but it represents a very serious challenge to those building the experimental equipment. High resolution spectrometers ($\Delta p/p = \sim 5\times10^{-5}$) are essential if the program is to achieve its maximum potential, and the short flight path of the kaon may pose special difficulties in the design.

The study of parity violating effects in electron scattering is a good way to study the weak interactions. Any parity violating asymmetry, such as

$$A = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \tag{3}$$

where σ_L and σ_R are the total cross sections for left-handed and right-handed electrons, respectively, measures the interference between the one photon exchange diagram and the exchange of the Z^0. Since the one photon exchange diagram falls off as $1/Q^2$, while the Z^0 diagram is approximately constant in Q^2, the asymmetry grows as Q^2. However, since the total cross section falls as Q^{-4}, the "figure of merit" for asymmetry measurements, $A\sqrt{\sigma}$, is independent of Q^2, so that the weak interference term can be studied over a wide range in Q^2. A number of interesting tests of the standard model have been proposed[1,3].

Planning for the experimental program at CEBAF will be a continuing process for the next five or more years. The immediate activities we look forward to are the 1985 Summer Workshop, to be held from June 3-7, followed by a three month Summer Study Group which will meet at the Newport News site. Activities will continue through 1985-86, and more programs will be planned for the summer of 1986. The CEBAF management welcomes the participation of users from all sub-fields of nuclear physics; do not hesitate to join the users group and participate in these activities.

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EXPERIMENTAL ASPECTS OF THE CEBAF PROGRAM

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ABSTRACT

Experimental aspects of the CEBAF program are discussed. Some examples are presented for physics problems that drive the requirements for the experimental facilities. Possible solutions are given.

I. INTRODUCTION

The CEBAF accelerator proposed to be built in Newport News (Virginia) will provide a high intensity electron beam with ≈90% duty-cycle in the energy range (.5-4.0) GeV. A detailed description of the accelerator and the physics program will be found in ref. /1/. In the following report a few experiments are discussed that require several of the specific features of the facility, like e.g. high energy, high intensity, high duty-cycle, good energy definition, capability to handle large data rates in the on-line and off-line analysis.

II PHYSICS ISSUES

1. (e,e'C) experiments

A large class of experiments at CEBAF will require the detection of the scattered electron e' in coincidence with a charged hadron C. The high duty-cycle of the beam will reduce accidental coincidences by nearly two orders of magnitude compared to present accelerators and will make the investigation of rare events possible. The most demanding experiment in terms of kinematic flexibility is (e,e'p); very low counting rates and high backgrounds are encountered in (e,e'k^+) experiments.

1.1 (e,e'p)

A large fraction of the CEBAF activities will be devoted to experiments in which the scattered electron is detected in coincidence with an outgoing proton (or any hadron). The original motivation for the (e,e'p)-experiments was to study the momentum distribution of bound protons as a function of their separation energies. This scope has now been enlarged to include all information one can get from this type of reaction.

Using unpolarized particles in the initial and the final state 4 different structure functions can be determined experimentally /2/. The kinematical situation is shown in fig. 1. The structure functions depend on q and ω (characterizing the virtual photon) and on the proton energy E_p and emission angle Θ_p relative to $\vec{q}$. Two structure functions can be obtained by performing the familiar Rosenbluth separation: keeping q and ω constant while changing the electron scattering angle Θ_e. The additional two structure functions (which are due to transverse-transverse and transverse-longitudinal interference terms and therefore sensitive to channel coupling and final state interaction effects) are responsible for a φ-variation of the differential cross sections at fixed q, ω, E_p and Θ_p. φ is the angle between the electron scattering plane and the decay plane of the hadronic system. The determination of all 4 structure functions requires a variation of φ; if small modulations are to be detected a large lever arm corresponding to the full φ range would be required.

1.2 (e,e'K) and hypernuclear physics

Most of our present knowledge on the level scheme of hypernuclei comes from (K^-, π^-) exchange reactions /3/. This reaction offers the advantage that the Λ-nucleon mass difference can be essentially compensated by the K-π mass difference leading to recoilless Λ-production and therefore to large cross sections for hypernuclear production. The overall energy resolution that has been reached is $\approx$ 3 MeV /4/. The big disadvantage is, however, the large distortion induced by both the incoming K^- and the outgoing π^- making the study of heavy hupernuclei impossible and, generally, a quantitave interpretation of the results difficult.

In contrast, the electromagnetic excitation of hypernuclei offers the advantage that the nucleus is practically transparent to the incoming photons; the outgoing K^+ have less interaction than the K^- (because the $\bar{s}$ quark in the K^+ cannot annihilate with a valence quark in the nucleon to form a 3-quark resonance). The clean production mechanism and the low distortion in the final state make the electromagnetic production of hypernuclei an excellent program for a multi-GeV accelerator.

The cross sections for the excitation of hypernuclear levels are mainly governed by

(a) the cross section for the elementary $\gamma p \rightarrow K^+\Lambda$ reaction.
(b) by the momentum transfer to the final nucleus.

Small momentum transfer ($q \lesssim 250$ MeV/c) is only reached for photon energies $E_\gamma \approx 2$ GeV/c and very small K^+ laboratory angles: $\Theta \lesssim 8°$. Detailed cross section calculations have been performed by several authors /5,6/; in the following example the calculation by T. W. Donnelly /6/ for the transition $^{12}C \rightarrow {}^{12}B(1\ g.s.)$ has been used. The cross section for the $(e,e'K^+)$ reaction at E_o = 4 GeV, E' = 2 GeV, $\Theta_{e'}$ = 10°, Θ_{K^+} = 10° (in the direction of $\vec{q}$) is

$$\frac{d^3\sigma}{d\Omega_e d\Omega_k dE'} \simeq 5\cdot 10^{-34} \frac{cm^2}{Sr^2 \cdot GeV}$$

Assuming electron and kaon spectrometers with $\Delta\Omega$ = 10 msr and $\Delta p/p = \pm 5\%$, a beam current of 50 μA on a 0.1 g/cm² target yields 450 events/day (for a 50% survival chance and an overall efficiency of 70%). The signal to accidental ratio is ≈ 20. To achieve a resolution of 400 keV for the excitation energy of the hypernuclear system the incident beam energy has to be known to $\Delta E_0/E_0 = 5\cdot 10^{-5}$ and both e' and K^+ momenta have to be measured to 10^{-4} accuracy. Since the CEBAF electron beam is expected to have 0.1% momentum uncertainty double arm dispersion matching techniques have to be used. The operation of two large acceptance spectrometers close to the beamline will require excellent background reduction. Also, the K^+ spectrometer has to be very short (≈10 m for a central momentum of 1.75 GeV/c) to keep the losses due to K^+ decay small.

2. e^- scattering involving polarized hadrons

In many cases unique (or higher quality) information can be obtained by using polarized hadrons (either a polarized target in the initial state or analyzing the polarization of the outgoing hadron). Two examples are given:

2.1 Separation of the deuteron form factors

The deuteron as a spin 1 object has 3 form factors which can only be separated using polarization. Especially the charge form factor is very sensitive to small admixtures to the deuteron wave function (e.g. due to 6-quark components). The tensor polarization of the recoil deuteron in elastic e d scattering which depends on the interference between the small charge and the dominant quadrupole form factor has recently been measured at relatively low q^2 at the MIT /7/; the measurements will be extended to higher q^2. An alternative method would be the use of a tensor polarized target /8/.

2.2 Neutron electric form factor

While the neutron magnetic form factor can be measured by performing a standard Rosenbluth separation in quasifree e n-scattering the electric part is largely undetermined due to its smallness. Again, the problem can be solved by using interference effects: the asymmetry that can be measured in the scattering of a polarized e^- off a polarized neutron depends on the interference between the electric and the magnetic part of the neutron form factor. Alternatively, the polarization transfer from a polarized e^- to the neutron could be observed. This would require a second scattering to determine the neutron polarization.

3. Electromagnetic properties of the nucleon resonances

The electromagnetic properties of 3-quark systems provide a very sensitive test for the quark wave functions, far better than the level scheme (which mainly reflects the underlying group structure) or the hadronic decay modes (which are difficult to calculate in the absence of a reliable QCD calculation for the strong coupling limit).

Therefore, the measurement of the electromagnetic coupling at the γNN^* vertex for real and virtual photons provides the best way to test the dynamical features of microscopic quark models.

Most of the information on the electromagnetic properties of the nucleon resonances have been obtained by exciting a nucleon to a resonance N^* using real photons and observing the subsequent πN decay. By comparing the $\gamma N \to N^* \to \pi N$ process with $\pi N \to N^* \to \pi N$ one obtains the coupling constant at the γNN^* vertex. In practice the situation is complicated because

(1) the resonances are broad and overlapping.
(2) there is background from nonresonant π-production,
(3) the experimental information on $\gamma N \to \pi N$ is far from being complete.

The $\gamma N \to \pi N$ reaction is described by 4 complex helicity amplitudes which are functions of two kinematical variables, e.g.: s (c.m.s. energy) and t (momentum transfer) or the photon energy k and the pion c.m.s. angle Θ_π. The experimental determination requires seven different measurements to be made at each kinematical setting (one phase is arbitrary). For most reaction channels, only differential cross sections and single polarization data are presently available.

Despite the unsatisfactory experimental situation the photocouplings of many nucleon resonances have been determined with some accuracy using the pion photoproduction data accumulated in the last two decades /9/. However, the couplings of those resonances that are only weakly excited in γN reactions could not be determined. This is essentially an experimental problem that can be solved by measuring accurate data sets for all necessary observables over the complete range of kinematical variables.

To reduce the influence of experimental errors and to get rid of discrete ambiguities, it will be useful to complement the 7 mandatory measurements by additional double polarization experiments. Especially the combination of circularly polarized photons (from the bremsstrahlung of polarized electrons) and a polarized proton or deuterium target promises to give high quality results; no such measurements have been performed up to now.

With increasing excitation energy the decay $N^* \to \pi N$ is suppressed in favor of decay modes like $N^* \to \pi\Delta$ or $N^* \to \rho N$. Therefore, these resonances are only weakly excited in πN reactions and are very difficult to observe in elastic πN scattering. (This might explain that theoretical models predict far more resonances than have been observed in πN scattering.) On the other hand, the coupling to the γN channel can still be reasonably strong. This offers the unique possibility to search for these resonances in $\gamma N \rightarrow \pi\pi N$ reactions /10/ since γN is the only decay channel available in a formation experiment.

The measurements with real photons ($q^2=0$) have to be extended to space-like virtual photons ($q^2 < 0$) using electron scattering. This gives additional information on the dynamical structure of the process under investigation. In the case of the investigation of the nucleon resonances, the electromagnetic form factors for the transition $N^* \rightarrow N\gamma$ can be determined (for a review see/11/). In the limit $q^2 \rightarrow 0$ the form factors turn into the photocouplings measured with real photons.

However, in electron scattering it is more difficult to obtain complete experimental data sets. Compared to real photons, all measurements have to be made as a function of the additional variable q^2 and for three photon helicity states.

III EXPERIMENTAL FACILITIES

The present layout of the CEBAF experimental area /12/ sees two end stations for high intensity beams (with heavy shielding and beam dump) and one end station for one or several low intensity beams which initially would be obtained by peeling off a small fraction of the primary beam. One of the high intensity areas will be equipped with magnetic spectrometers; the low intensity hall will house a large acceptance detector.

1. Magnetic Spectrometer Arrangement

At each electron accelerator two or three magnetic spectrometers on a common pivot serve as the general purpose setup for the investigation of inclusive e^- scattering and for coincidence experiments. High momentum resolution can be obtained by proper shaping of the magnetic fields; well shielded detector systems far away from the target tolerate a high flux of particles. Finally, the existence of focal planes and the decoupling of angle and momentum measurement makes it easy to take and analyze a large number of events. The design specifications for the spectrometers have been discussed at several workshops; the current values are listed in table 1 /13/. Compared to present high resolution spectrometers a considerable improvement in the product $(\Delta p/p)*\Delta\Omega$ has been foreseen requiring new experimental techniques like superconducting quadrupoles (with fields of 3-4 Tesla at the pole tips) between the target and the first dipole to keep the gap height in the dipoles as small as possible. A general goal in the design will be to achieve very high resolution by making the higher order coefficients vanish in the central part of the acceptance. By tuning the properties of the spectrometer the same instrument can be used in a high resolution/low acceptance or a lower resolution/larger acceptance configuration.

1.1 Out-of-plane measurements

Several possibilities have been investigated for out-of-plane measurements:

a) For low q^2, the electron spectrometer can be set to very small angles. If the vertical acceptance for the electron is large one could cover a wide φ-range in one setting.

b) For small hadron laboratory angle (with respect to $\vec{q}$) a medium acceptance hadron spectrometer could cover the complete φ range. Small hadron angles are important for quasifree knockout reactions (which usually exhibit high cross sections in the $\vec{q}$ direction) or for reactions that benefit from a large Lorentz boost (e.g. in the process $eN \rightarrow e'\pi N'$ it is much easier to cover a large φ-range by detecting the N' than the π because the Lorentz boost concentrates the N' in a small cone around the $\vec{q}$ direction regardless of the N' c.m.s. angle).

c) For large q^2 and large Θ^{lab} the problem can no longer be solved in one setting (covering a small solid angle only). Then, either one of the spectrometers has to be physically moved out of the horizontal plane or the incident beam has to be moved out of the plane defined by the two spectrometers.

d) For reactions that require low resolution magnetic analysis only (like e.g. (e,e'p)-reactions on light nuclei) a possible solution would be to use a large acceptance detector (see the following section) and a weak intensity beam.

2. Large Acceptance Detector

Typical experimental problems that can be handled only by a large acceptance detector are

1. The detection of multiple particle final states (high detection efficiency and a model-free analysis for these events can only be achieved by detectors with a complete coverage of the angular and energy range for all outgoing particles).

2. Measurements at limited luminosity (target density * beam intensity). The limitation can be due to the target (rare or dangerous elements, active targets, polarized targets with low radiation resistance) or due to the beam (e.g.: tagged photon beam).

For photon beams, only solid targets are applicable because of the large target thickness required. These targets can also be used in a weak (some nA) electron beam. If a circulating electron beam with high intensity (some 100 mA) is available, an alternative method is the use of an internal (low density) polarized jet target. Since in both cases the luminosity is relatively low ($\leq 10^{33}/cm^2\cdot sec$) a large acceptance detector is required for reasonable count rates.

2.1 General design considerations

The general properties of a large acceptance detector suitable for a broad range of experiments are listed below.

1. Homogeneous coverage of a large angular range for charged particles (magnetic analysis), photons (total absorption counters) and neutrons (to some extent).

2. Good energy and angular resolution (for all particles).

3. Good particle identification properties.

4. No transverse magnetic field at the beam axis (to avoid sweeping $e^{\pm}$ pairs into the detector).

5. Large field free space around the target to allow for the installation of complicated targets (cryogenic, polarized, track sensitive, etc.).

6. Symmetry around the beam axis.

7. Larger $\int B d\ell$ for particles going forward than for particles going sideways.

8. High count rate capability; detector should work in a tagged photon beam ($N_\gamma = 10^7\,\gamma/sec.$) or a weak electron beam (e.g., 10nA on a 1 g/cm^2 target $\twoheadrightarrow$ luminosity $\leq 10^{34}/cm^2\cdot sec$).

2.2 Description of a large toroidal detector.

Most of the requirements listed above can be satisfied by using a toroidal magnet consisting of 8 coils arranged around the beam line to produce essentially a magnetic field in φ-direction. Drift chambers will track charged particles; scintillation counters will be used for the trigger and for time-of-flight; shower counters will detect photons. A sketch of the detector is shown in figure 2. A description of its main features is given below.

1. Magnetic field

   The magnetic field is generated by a set of 8 super-conducting coils. The total current in each coil is of the order of 10^6A. The strong forces that pull the coils towards the axis (some hundred tons/coil) can be handled by using a cold ring around the beam line to support all coils. This will require one common vacuum system for the whole assembly. For particles emitted at $\Theta = 90°$ about 20% of the φ-range are obstructed by the vacuum chamber.

2. Tracking chambers

Charged particles will be tracked by three sets of planar wire chambers, one situated roughly at the peak of the magnetic field and two just outside of the coils. The chambers, each consisting of several layers of staggered sense wires, should determine the position precisely and should also give some direction information to facilitate track reconstruction for multiple hits in the same sector.

3. Scintillation counters

The outer planar drift chambers are completely surrounded by scintillation counters which serve the double purpose of providing the trigger and time-of-flight information. Also, a fraction of the high energy neutrons ($\approx$5%) will interact in the outer scintillation counters and will thus be detected.

4. Shower counter

The detector is completely surrounded by shower counters for the detection of high energy photons from Compton scattering, π°, η decays, etc.) Due to the size of the counter ($\simeq 80^2$m , $\simeq$100 tons) inexpensive material and construction techniques (e.g., a sandwich of lead plates interleaved with active material like scintillators or gas detectors) have to be used. The shower counter can also help to identify charged particles; especially high energy muons from π or K decays (that are difficult to separate from pions using time-of-flight) will show up clearly in the shower counter because their energy deposition is constant with depth.

5. Special configurations

The detector can easily be converted into a pair spectrometer for the precise analysis of high energy photons or into a recoil nucleon polarimeter by inserting a suitable material between the target and the first drift chamber. Possible applications include Compton scattering or the measurement of the recoil nucleon polarization in the photoexcitation of the nucleon resonances and in deuteron photodisintegration.

IV SUMMARY

Physics issues have been discussed that drive the requirements for the experimental facilities at CEBAF. The experimental program will concentrate on the structure of 2- and 3-quark systems and on the electromagnetic properties of (especially light) nuclei. Experimental techniques will include the use of magnetic spectrometers capable of operating in a high intensity environment and the operation of large $\Delta\Omega$ (close to 4π) detectors for multiple particle final states or limited luminosity situations. In many cases the experimenter has a choice between a high and a low luminosity setup for the same experimental quantity.

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Table 1 Magnetic spectrometers for CEBAF				
#	p_{max} [GeV/c]	$\delta p/p$ [10^{-4}]	$\Delta p/p$ [%]	$\Delta\Omega$ [msr.]
1a	4	2	10	20
1b	4	0.2	5	5
2a	2	5	10	20
2b	2	0.5	5	15
3a	1	10	20	70
3b	1	1	10	20

Figure Captions

Fig. 1 Kinematics of the (e,e'C) reaction

Fig. 2 Large acceptance detector
a) cut perpendicular to the beam direction
b) cut along the beam direction

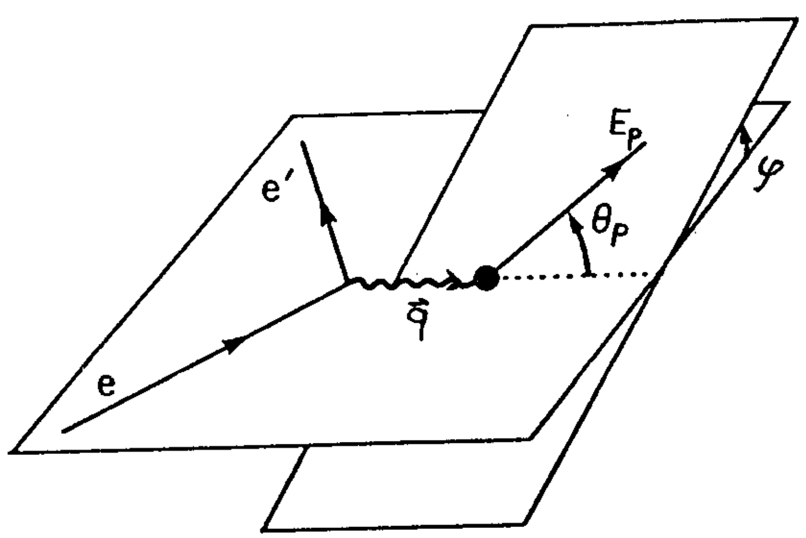


Fig. 1

Fig. 2a

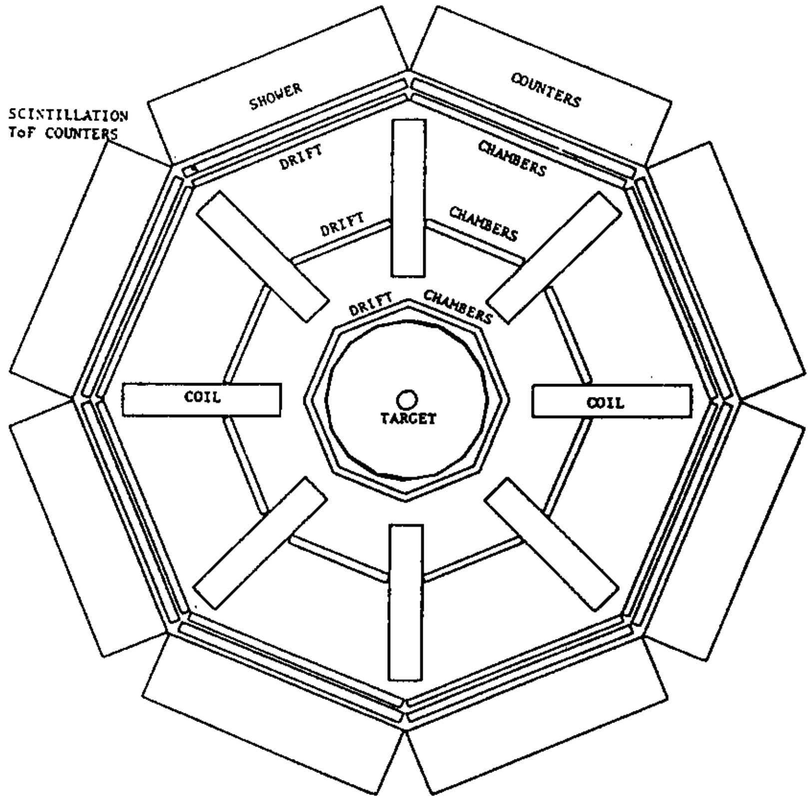
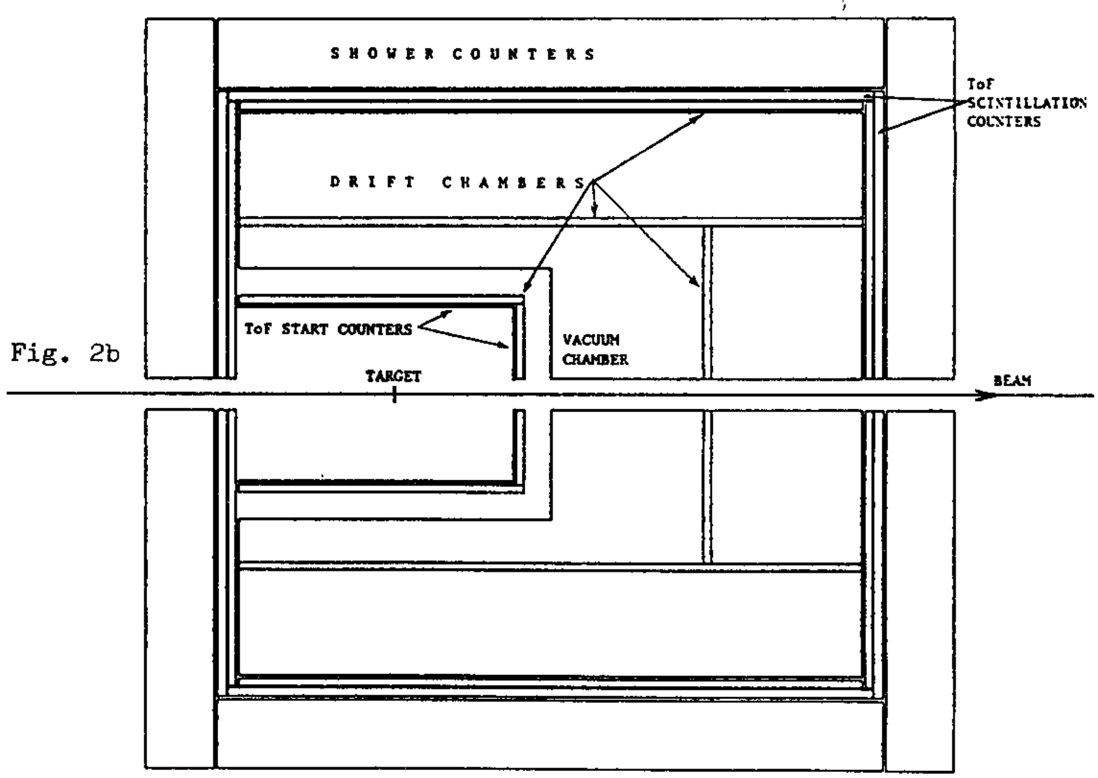

SCINTILLATION
ToF COUNTERS
SHOWER
COUNTERS
DRIFT
CHAMBERS
DRIFT
CHAMBERS
DRIFT
CHAMBERS
COIL
TARGET
COIL

Fig. 2b


SHOWER COUNTERS
ToF
SCINTILLATION
COUNTERS
DRIFT CHAMBERS
ToF START COUNTERS
VACUUM
CHAMBER
TARGET
BEAM